N 81-17264

NASA Technical Memorandum 81683

Dynamics of Solid Dispersions in Oil During the Lubrication of Point Contacts, Part I—Graphite

C. Cusano
University of Illinois
Urbana, Illnois

and

H. E. Sliney
Lewis Research Center
Cleveland, Ohio

Prepared for the
Annual Meeting of the American Society
of Lubrication Engineers
Pittsburgh, Pennsylvania, May 11-14, 1981

NASA

DYNAMICS OF SOLID DISPERSIONS IN OIL DURING THE LUBRICATION OF POINT CONTACTS, PART I - GRAPHITE

C. Cusano, Member ASLE
Department of Mechanical and Industrial Engineering
University of Illinois at Urbana-Champaign
Urbana, IL 61801

and

H. E. Sliney, Fellow, ASLE
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

E-410-1

ABSTRACT

A Hertzian contact is lubricated with dispersed graphite in mineral oils under boundary lubrication conditions. The contacts are optically observed under pure rolling, combined rolling and sliding, and pure sliding conditions. The contact is formed with a steel ball on the flat surface of a glass disk. Photomicrographs are presented which show the distribution of the graphite in and around the contact. In addition, friction and surface damage are shown for conditions when the base oils are used alone and when graphite is added to the base oils. Under pure rolling and combined rolling and sliding conditions, it is found that, for low speeds, a graphite film can form which will separate the contacting surfaces. In contrast, under pure sliding conditions, graphite accumulates at the inlet and sweeps around the contact, but very little of graphite passes through the contact. The accumulated graphite appears to act as a barrier which reduces the supply of oil available to the contact for boundary lubrication. Friction data show no clear short term beneficial or detrimental effect caused by addition of graphite to the base oil. However, during pure sliding, more abrasion occurs on the polished balls lubricated with the dispersion than on those lubricated with the base oil alone. All observations were for the special

case of a highly-polished ball on a glass surface and may not be applicable to other geometries and materials, or to rougher surfaces.

INTRODUCTION

The reason often given for adding graphite to oils is to reduce the friction and wear under mixed-film or boundary lubrication conditions. However, only limited data are available which substantiate the beneficial effects of graphite in oils. Among these are data obtained by Smith (1), Rosenberg and Campbell (2), and Stock (3). Bartz (4), on the other hand, has observed that the addition of graphite to oils reduces its antiwear performance. Other investigators (5,6) have found that the addition of graphite to mineral oil can have beneficial or detrimental effects on the antiwear performance of these oils depending on the type of machine used to test the dispersions, other types of additives in the oils, particle hardness and particle size of the graphite, and load.

The results so far reported on the performance of oils containing graphite suggest that additional investigations are needed to more fully understand the behavior of graphite dispersions in oils. Toward this end, it is of interest to optically observe the dynamic behavior of graphite dispersions in concentrated contacts. The dynamics of dry graphite in concentrated contacts have been observed by Sliney (7). However, to the knowledge of the authors, no observations have been reported on the dynamic behavior of graphite dispersions in concentrated contacts. It is the main purpose of this paper to report on such observations.

EXPERIMENTAL APPARATUS

The basic components of the apparatus consist of a steel ball which rides against a pyrex disk. The contact formed was viewed through the pyrex disk by means of a microscope. It was determined that, the disk should not

be coated as is customary for EHD film thickness measurements) because any type of coating on the disk reduces the visibility of the graphite dispersions. A xenon lamp was used as the light source for both visual observations and for taking photomicrographs. Light from this source was passed through a combined red and green filter system.

The general configuration of the experimental apparatus is shown in Fig. 1. The apparatus has been used for numerous EHD studies and described in detail elsewhere (8). For rolling experiments the ball is rotated by a motor-driven quill. The only modification made for the present study is the addition of a variable speed dc motor directly coupled to the transparent pyrex disk. With this modification, the ball and disk speeds can be independently controlled and the apparatus can be operated under pure rolling, pure sliding, or combined sliding and rolling conditions. The pure sliding data were obtained by rotating the disk and keeping the ball fixed. All the data and photomicrographs presented in this study were taken at a room temperature of 25±2° C and a room relative humidity of 30±5 percent.

TEST MATERIALS

The balls used in this investigation are 0.02063 m in diameter and made of AISI 52100 steel. They are highly polished, having a nominal surface roughness of less than 0.018 μm rms (0.7 μin.) and their hardness is approximately 65 Rc. The elastic modulus and Poisson's ratio for the balls are 21×10^{10} N/m^2 (30×10^6 psi) and 0.30, respectively. The transparent disk is 0.102 m in diameter, 0.006 m thick, and is made of commercial grade pyrex. The nominal surface roughness of the pyrex is less than 0.03 μm rms (1.2 μin.). It should be noted that even though the surface topographies of all the disks used were relatively uniform, there were some variations in the thickness of the disks. The most uniform disk had a thickness variation

of 28 μm (0.0011 in.) and the least uniform disk had a thickness variation of 114 μm (0.0045 in.). The elastic modulus of the pyrex is approximately 7.6×10^{10} N/m^2 (11×10^6 psi) and its Poisson's ratio is approximately 0.25.

Coarse and suspension size particles of commercial lubricant grade graphite powders were investigated. The graphite was supplied as concentrates in highly refined paraffinic base oil. The particle size of the suspension grade was less than 0.5 μm. The suspension concentrate contained 10 weight percent of graphite and the viscosity of the suspension was 180 cS at 37.8° C. The particle sizes of the coarse graphite were mainly in the range of 25 to 50 μm and did not exceed 100 μm. The concentration of the coarse graphite in oil was 40 percent by weight and had a paste-like consistency. The two concentrates were diluted with various amounts of two super-refined paraffinic mineral oils of different viscosities. Dispersions with 0.5, and 3.0 percent by weight of suspension grade graphite and coarse grade graphite were made. The fluid properties of the base mineral oils and the particle sizes of the two grades of graphite are summarized in Table 1.

PROCEDURE

Before a test series is begun, the pyrex disk and ball are thoroughly cleaned with a solvent. After the disk is cleaned, six drops of dispersed graphite are oriented in a circular pattern on the disk. This pattern approximately corresponds to the circular path formed by the contact between the ball and the disk. It should be noted that six drops of dispersed graphite is more than adequate for flooding the contact.

Table 2 gives the matrix of condition for the various experiments in a test series for each lubricant. The primary variables in each series are load, and the velocities of the two surfaces. The relevant velocity terms

are the disk velocity u_1, the ball velocity u_2, the sliding velocity $u_1 - u_2$, and the entraining velocity $\overline{U} = 0.5\ (u_1 + u_2)$. $\overline{U}$ is the velocity used in elastohydrodynamic film thickness calculations. The slide/roll ratios are defined as $\sum = (u_1 - u_2)/0.5(u_1 + u_2)$. It follows that $\sum$ is equal to zero for pure rolling and 2:0 for pure sliding when one surface is stationary.

Note that each test series is comprised of twelve experiments. Since there are two grades of graphite, two oils, and three concentrations of dispersion, (0, 0.5, and 3.0 percent) the total number of experiments in this matrix is 12x2x2x3 = 144. Some additional experiments outside of the matrix were also conducted. In order to limit the number of balls and disks used to a reasonable number, each test series is conducted on a separate track on the disk and a separate ball, but every experiment in a single series for a given lubricant employs the same track and ball. To check the validity of this approach, limited data were obtained for cases in which different specimens were used in each experiment. The dynamic behavior of the graphite dispersions observed in these experiments did not differ from their behavior in experiments performed in series on the same tracks.

Friction coefficients were measured continuously during the experiments. Photomicrographs to illustrate the distribution of graphite in and around the contacts were taken periodically. Low speeds were used in order to more easily observe the dynamics of the dispersed graphite, and to minimize hydrodynamic effects.

To check the possibility of hydrodynamic effects, calculations of the elastohydrodynamic film thicknesses for the more viscous base oil were made using Cheng's equation (9) for the contact of a ball on a flat under isothermal conditions. The results are given in Table 3. These results show

that, even under the most favorable conditions in the experimental program for EHD film formation (1 kg load, 0.0073 m/s entraining velocity, and using the more viscous, 150 cS, base oil), the calculated oil film thickness is only 0.013 μm (0.51 μin.). The composite surface roughness of the ball and the disk is 0.35 μm (1.4 μin.). Therefore the film thickness parameter, λ, which is the ratio of film thickness to the composite surface roughness is only 0.36. According to the arguments developed in (10), at λ less than 1.0, asperity contacts occur and at the much lower λ of 0.36, lubrication is in the boundary lubrication regime with the possibility of some micro-EHD effects. It is in this regime that dispersed graphite is most likely to enhance lubricant film thickness or otherwise influence the lubrication process.

RESULTS

The experimental results will be presented in the following form:

(a) Photomicrographs of graphite distribution during the experiments

(b) Coefficient of friction data

(c) Photomicrographs of wear surfaces after a test series

Dynamic of Graphite Dispersions

Figures 2 to 4 show the distribution of solid lubricant dispersions under various conditions. The inlet, in all of these figures, is on the left side and the exit is on the right side of the figures. The results presented in these figures are representative of the many photomicrographs which were taken. Each of the photomicrographs shows the contact at some time in the test series that is summarized in Table 2.

Pure rolling. - Figure 2 shows the contacts, subjected to a load of 2 kg, under pure rolling conditions. The graphite concentration for Figs. 2(a) and (b) is 0.5 percent while that for Figs. 2(c) and (d) is 3 percent.

These concentrations encompass concentrations generally used in practice. From Fig. 2, the following observations can be made: (a) for low rolling velocities, the graphite particles become "packed" between the two rolling surfaces and a "track" of graphite is formed which separates the two rolling surfaces; (b) with a 0.5 percent concentration of suspension grade graphite a more uniform "track" is formed than with a 0.5 percent concentration of coarse grade graphite; (c) with a 3 percent concentration of graphite a continuous "track" is formed for both suspension and coarse grade graphite; and (d) little difference is observed between the results obtained with base oils I and II.

The graphite track is more difficult to form as the rolling velocity is increased. For example, with a rolling velocity of 0.0146 m/s, the track was barely visible after 8 minutes of running time when using a 0.5 percent concentration of suspension grade graphite in oil I. At higher rolling velocities, the graphite particles go around the contact to a much greater extent than at lower rolling velocities.

Combined slide/roll. - Figure 3 shows the contact under slide/roll conditions when lubricated with 0.5 and 3 percent graphite dispersions. The disk velocity is 0.0021 m/s while the peripheral velocity of the ball is 0.0007 m/s. This combination gives a slide/roll ratio of one. As with pure rolling, the graphite is drawn into the contact and the surfaces are separated by a graphite film in all cases except the example in Fig. 3(b) which is for 0.5 percent coarse graphite in 150 cS oil. In this figure, a faint track can be seen, but the amount of coarse graphite drawn into the contact is relatively small compared to the amount of suspension grade graphite in the contact of Figs. 3(a) and (c). However, Fig. 3(d) shows that an appreciable graphite film is formed from the more concentrated (3 percent)

coarse graphite dispersion. Note that in mixed sliding and rolling, graphite tends to accumulate at the inlet and the inlet then acts as a reservoir from which graphite feeds into the contact. No such accumulation at the inlet is seen for the pure rolling condition. For pure rolling or mixed slide/roll conditions, and for a 0.5 percent concentration at very low speed, a continuous graphite film is more readily formed with suspension grade graphite than with coarse graphite. At the 3 percent graphite concentration however, the effect of particle size is less apparent.

Pure sliding. - Photomicrographs of the contact under pure sliding conditions are shown in Fig. 4. The load is 1 kg and the sliding velocity is 0.0021 m/s. The most general observation which can be made is that, to various degrees, the graphite accumulates at the inlet. However, packing of the solid lubricant does not seem to occur. Graphite particles generally flow backward near the center portion of the inlet and are transported to the left and right from this central portion around the contact. An indication of backflow in the inlet region can be seen in Fig. 4(b). The amount of graphite going through the contact seems to be very small. Another obvious feature in most of the photographs is the presence of partial Newton rings or interference light fringes around the contacts. Since oil and glass have nearly the same refractive indices and the glass is not coated, interference fringes can only be seen in those areas around the contact where there is an almost complete absence of oil. This suggests that the graphite accumulation at the inlet may be blocking some of the oil supply to the immediate vicinity of the contact thus creating a condition of lubricant starvation.

In other experiments, loads of up to 4 kg and sliding velocities up to 0.0146 m/s were used. The performance of the dispersion is about the same

as that represented in Fig. 4. However, some differences are noted: (a) At 0.0146 m/s and 1 kg, a partial graphite film forms in the contact compared to essentially no film at the lower velocity. This is an interesting contrast to the pure rolling case where higher velocities discourage graphite film formation; (b) at 0.0146 m/s and and 4 kg, some graphite is again observed in contact but the amount is inadequate and considerable wear occurs.

Coefficient of Friction

Friction coefficients for pure rolling were 0.002±0.001 in all cases. For a slide/roll ratio of one, friction coefficients were 0.04±0.01 in all cases. The variations in these quantities are within the normal experimental scatter and showed no measurable influence of dispersed graphite on the friction coefficient. For pure sliding, measurable differences, greater than any experimental error or scatter, were observed. Nevertheless, as will be seen, no clear beneficial or detrimental effect of graphite on the friction coefficient is apparent.

Friction coefficients as a function of load in pure sliding are presented in Figs. 5 and 6. The data compare the friction coefficients for 78 and 150 cS base oils alone and for 0.5, 1.0, and 3.0 weight percent concentrations of graphite in these oils. The following general observations can be made: (a) the friction coefficient is generally lower at 0.0146 m/s than at 0.0021 m/s; and (b) the higher viscosity oil generally gives lower friction than the lower viscosity oil. Both of these results are characteristic of boundary lubrication they do not show any marked, consistent effect of graphite upon the friction coefficient.

Wear

Because of the relatively low wear produced during a test series, no attempt was made to measure quantitative wear. However, a subjective, qualitative assessment of the severity of wear was made by examining numerous photomicrographs of worn balls. Figure 7 shows representative photomicrographs of tool steel balls after the sliding experiments. Oblique illumination was used so that the highly-polished areas appear black and the scratches or wear marks appear as white streaks. The surface damage consists primarily of scratches in the direction of sliding. Although the balls were not under load at the time the photographs were taken, a circular contact area is delineated by the scratch pattern in some cases. The scratches could have been caused by glass wear particles, abrasive contaminants in the graphite, or perhaps less likely, by the graphite itself. In any event the microscopic examination indicates that: (a) The scratches produced on the surface of the ball when the base oils alone are used as lubricants are not as pronounced or the same as the scratches produced when graphite is added to the base oils; (b) for the same oil, coarse grade graphite resulted in more damage to the contact than suspension grade graphite and (c) no consistent differences were noted in the surface damage from 0.5 and 3.0 percent concentrations of graphite.

One of the wear scars was examined by sputtering with xenon, and when performing an Auger Electron Spectroscopy depth profile analysis. By analyzing both the inside and outside of the wear scar, it was concluded that there is a shallow diffusion of graphite into the surface of the steel.

DISCUSSION

The results presented in this paper on the dynamics of graphite dispersions under pure sliding conditions are quite different than the published

results on the dynamics of dry graphite. With dry graphite, the particles readily enter the inlet and are drawn into the Hertzian contact where they are compressed and sheared into very thin films (7). With graphite dispersions, the amount of graphite going through the contact is relatively small under pure sliding conditions. Graphite does accumulate at the inlet at low speeds but it is not packed. This accumulation decreases as the speed is increased and it is doubtful that any accumulation would exist at most sliding speeds found in practice.

The different particle dynamics between dry and dispersed graphites can be more easily understood by noting that when graphite is used as a dispersion in oils, particles are more easily transported around the contact than when graphite is used dry. Such transport phenomena of the particles can be easily visualized by observing the motion of the carrier oil around the contact. In addition, when the particles are larger than the nominal film thickness, the tractive forces which must extrude the particles into the contact are smaller when the particles are wet with oil than when the particles are used dry.

One aspect of the dynamics of graphite dispersions which has not been completely investigated is the effect of surface topography on the transport of graphite in and around concentrated contacts under pure sliding conditions. The surfaces used to obtain the data presented in this paper were very smooth. It is possible that the graphite particles in contact with smooth surfaces are more likely to slip than if the particles were in contact with surfaces which were rougher. Therefore, it can be hypothesized that as the surface roughness increases, the graphite particles are more likely to be drawn into the contact. Preliminary data by the authors support this hypothesis.

It is reasonable to assume that, under pure rolling conditions, the effects of surface topography on the formation of graphite films are less important since the rolling motion tends to trap the particles between the contacting surfaces. The rolling speed in this case plays an important role. At very low speeds, the particles are easily trapped in the contact and relatively thick graphite films can be readily formed. At higher speeds, however, such films are more difficult to form. It is felt that graphite particles, at the higher speeds, are still momentarily trapped between the rolling surfaces, but do not adhere to the surfaces. At the higher velocities, the graphite, which is initially trapped by the rolling surfaces becomes detached by the flow and possibly cavitation of the fluid at the exit. This conclusion is supported by the fact that a graphite film, which is formed at low velocities, gradually disappears as the velocities are increased.

The behavior of graphite dispersions under mixed slide/roll conditions is (not surprisingly) intermediate between the behavior in pure sliding and in pure rolling. Because of the sliding component, surface topography might again have some significant effect on graphite transport into the contact.

An important result is the demonstration of partial lubricant starvation of the contact caused by the accumulation of graphite at the inlet under some slide/roll and pure sliding conditions, but not during pure rolling. This accumulation is beneficial to the degree that it acts as a reservoir of solid lubricant at the inlet. However, under conditions where the solid is not readily drawn into the contact, the graphite accumulation serves no useful purpose and in fact interferes with the supply of lubricant to the contact. The surface damage on the balls after sliding experiments show that there is generally more abrasion when the dispersions are used

than when the base oils are used alone. The damage is more severe when coarse grade graphite (which accumulates at the inlet more readily) is used than when suspension grade graphite is used. It is also possible that abrasive impurities in the graphite and glass wear particles may cause some of the scratches on the highly-polished surfaces of the tool steel balls.

CONCLUSIONS

The contact of a tool steel ball on a glass flat was lubricated with graphite dispersions. The conclusions that can be drawn as the result of this study are:

1. Under pure rolling conditions and low speed, the graphite particles are gradually packed and eventually a track of graphite is formed which separates the two surfaces. This graphite track is not as easily formed when the rolling speed is increased and high rolling velocity can actually remove a previously deposited graphite track.

2. Under pure rolling conditions, the graphite track is more complete and uniform when using suspension grade graphite than when using coarse grade graphite. This is especially true for relatively low concentrations of graphite.

3. For the operating conditions considered, the viscosity of the base oil did not significantly change the dynamics of the graphite dispersions when pure rolling conditions existed.

4. A graphite film is also produced when the surfaces are subjected to a slide-roll ratio of one and the speeds are low. As the speeds are increased, the graphite film is more difficult to form.

5. Under pure sliding conditions and low speeds, graphite accumulates at the inlet and the amount of graphite going through the contact is quite small. This accumulation may cause partial inlet starvation. As the sliding speed is increased, smaller amounts of graphite accumulate at the inlet, and the graphite has more of a tendency to form a film.

6. Coefficient of sliding friction data for the base oil and the dispersions indicate that, as expected, lower values are obtained at higher speeds and with higher viscosity oils. There was no clear beneficial or detrimental effects caused by the addition of graphite to the base oils.

7. Under sliding conditions, the surface damage caused when the base oil alone is used as the lubricant is generally not as severe as the damage caused when graphite is added to the base oils.

8. For the same base oil, coarse grade graphite tends to produce more surface damage to the contact than suspension grade graphite.

9. An analysis of the contact area on the ball indicates the likelihood that a diffusion of the graphite into the steel takes place.

ACKNOWLEDGEMENT

The authors wish to express their appreciation to John Ferrante at NASA-Lewis for conducting an Auger Electron Spectroscopy analysis on the wear scars.

REFERENCES

1. Smith, E. A., "Colloidal Graphite in Assembly Lubrication," Engineering, 165, 505-507 (1948).

2. Rosenberg, R. C., and Campbell, W. E., "The Effect of Mechanically Dispersed Solid Powders on Wear Prevention of White Oils at High Loads and Low Speeds," Lubr. Eng., 24, 2, 92-98 (1968).

3. Stock, A. J., "Evaluation of Solid Lubricant Dispersions on a Four-Ball Tester," Lubr. Eng., 22, 4, 146-152 (1966).

4. Bartz, W. J., "Solid Lubricant Additives - Effect of Concentration and Other Additives on Initial Wear Performance," Wear, 17, 421-432 (1971).

5. Hirano, F. and Yamamoto, S., "Four-Ball Test on Lubricating Oils Containing Solid Particles," Wear, 2, 349-363 (1958/1959).

6. Bartz, W. J. and Oppelt, J., "Lubricating Effectiveness of Oil Soluble Additives and Graphite Dispersed in Mineral Oil," ASLE Proceedings of the 2nd. Intenational Conference on Solid Lubrication, American Society of Lubrication Engineers, Park Ridge, IL (1978), ASLE SP-6, pp. 51-58.

7. Sliney, H. E., "Dynamics of Solid Lubrication as Observed by Optical Microscopy," ASLE Trans., 21, 2, 109-117 (1978).

8. Wedeven, L. D., "Traction and Film Thickness Measurements under Starved Elastohydrodynamic Conditions," J. Lubr. Technol, ASME Trans., 97, 2, 321-329 (1975).

9. Cheng, H. S., "A Numerical Solution of the Elastohydrodynamic Film Thickness in an Elliptical Contact," J. Lubr. Technol., ASME Trans., 92, 1, 155-162 (1970).

10. Tallian, T. E., Chiu, Y. P., Huttenlocker, D. F., Kamenshine, J. A., Sibley, L. B., and Sindlinger, N. E., "Lubricant Films in Rolling Contact of Rough Surfaces," ASLE Trans., 7, 2, 109-126 (1964).

TABLE 1. - LUBRICANT PROPERTIES

Base oil properties

	Oil I	Oil II
Gravity, °API	30.9	30.2
Viscosity at 98.9° C, cS	9.44	15.0
Viscosity at 37.8° C, cS	78	150
Viscosity index	106	106
Pour point, °C	-12	-12
Flash point, °C	232	238
Fire point, °C	277	293
Sulfur, wt., percent	0.02	0.02

Graphite particle size

	Suspension grade	Coarse grade
Particle size range, micrometers	less than 0.5	25 to 50

TABLE 2. - TEST SERIES

Experiment, no.	Load, kg	Maximum Hertz stress, N/m^2	Velocity, m/s		Slide/roll ratio $\frac{(u_1 - u_2)}{[0.5(u_1 + u_2)]}$	Comments	Duration of experiment, min.
			Disk u_1	Ball u_2			
1	2	5.0×10^8	0.0021	0.0021	0	Pure rolling	8
2	2	5.0×10^8	.0021	.0007	1	Rolling and sliding	8
3	2	5.0×10^8	.0063	.0021	1	Rolling and sliding	5
4	1	4.0×10^8	.0021	0	2	Pure sliding	8
5	1	4.0×10^8	.0063		2		5
6	1	4.0×10^8	.0146		2		5
7	2	5.0×10^8	.0021		2		8
8	2	5.0×10^8	.0063		2		5
9	2	5.0×10^8	.0146		2		5
10	4	6.3×10^8	.0021		2		8
11	4	6.3×10^8	.0063		2		5
12	4	6.3×10^8	.0146		2		5

TABLE 3. - CALCULATED OIL FILM THICKNESSES FOR 150 cS

PARAFFINIC OIL WITHOUT DISPERSED SOLIDS - 1 kg LOAD

Entraining velocity $\bar{U} = \frac{1}{2}(u_1 + u_2)$ m/s	Oil film thickness, h		Film parameter, $\frac{h}{\sigma} = \lambda$
	μm	μin.	
0.0011	0.003	0.13	0.09
.0014	.004	.15	.11
.0021	.005	.21	.16
.0032	.007	.28	.21
.0042	.009	.34	.25
.0073	.013	.51	.36

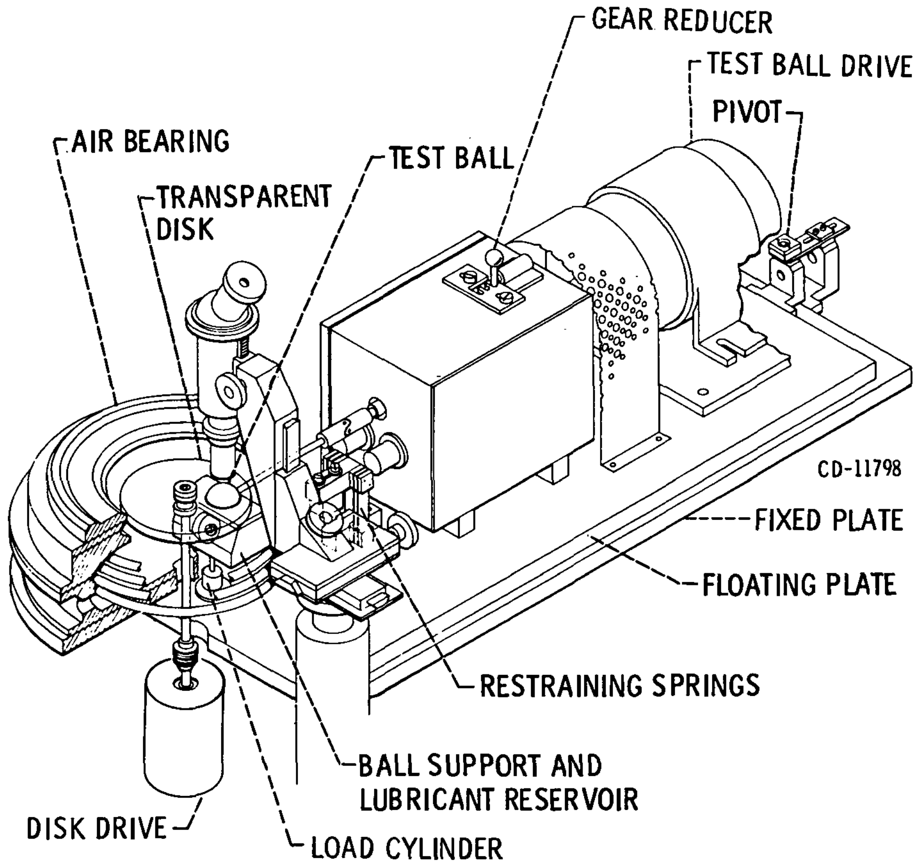
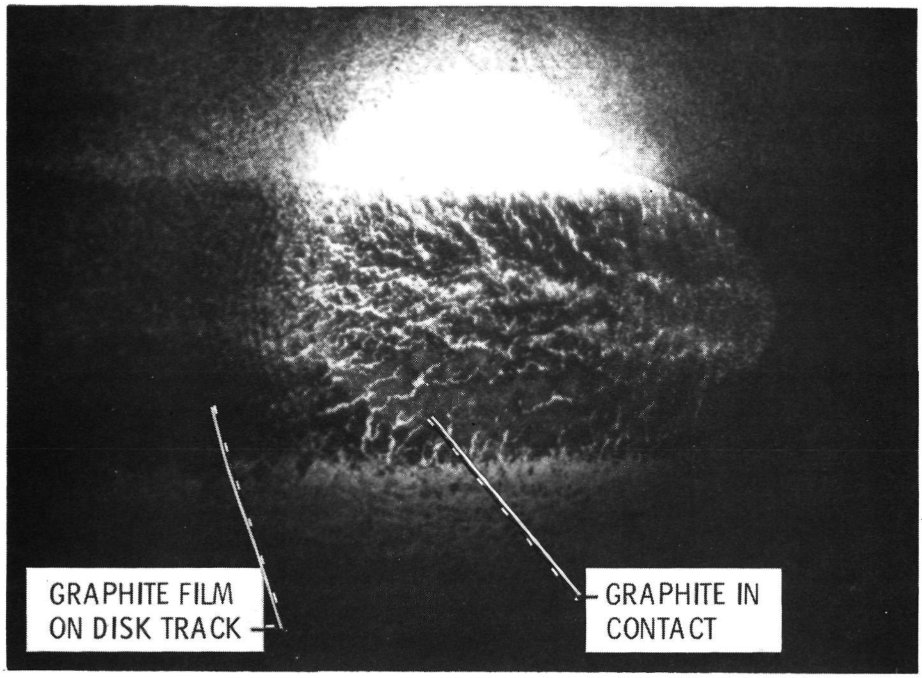
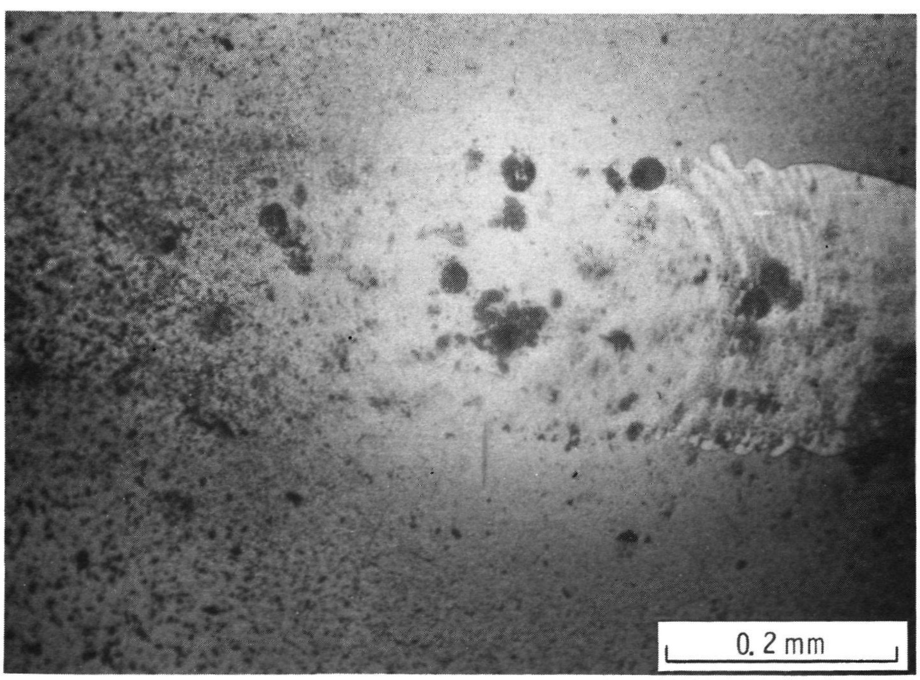


Figure 1. - Optical EHD rig.

INLET SIDE HERTZIAN CONTACT EXIT SIDE



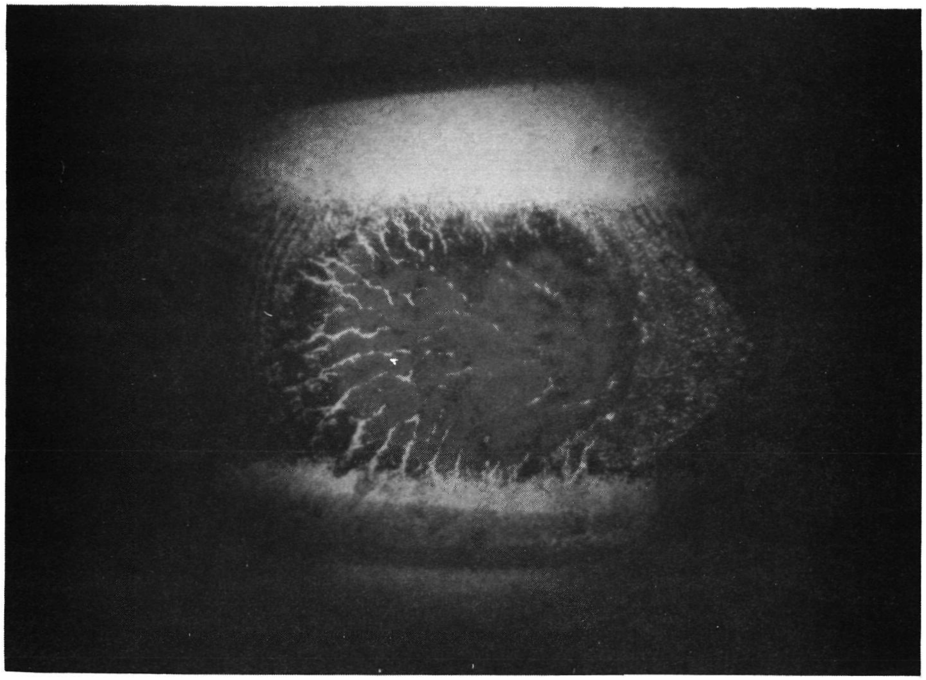
(a) 0.5 percent SUSPENSION GRADE GRAPHITE IN 78 cS OIL.



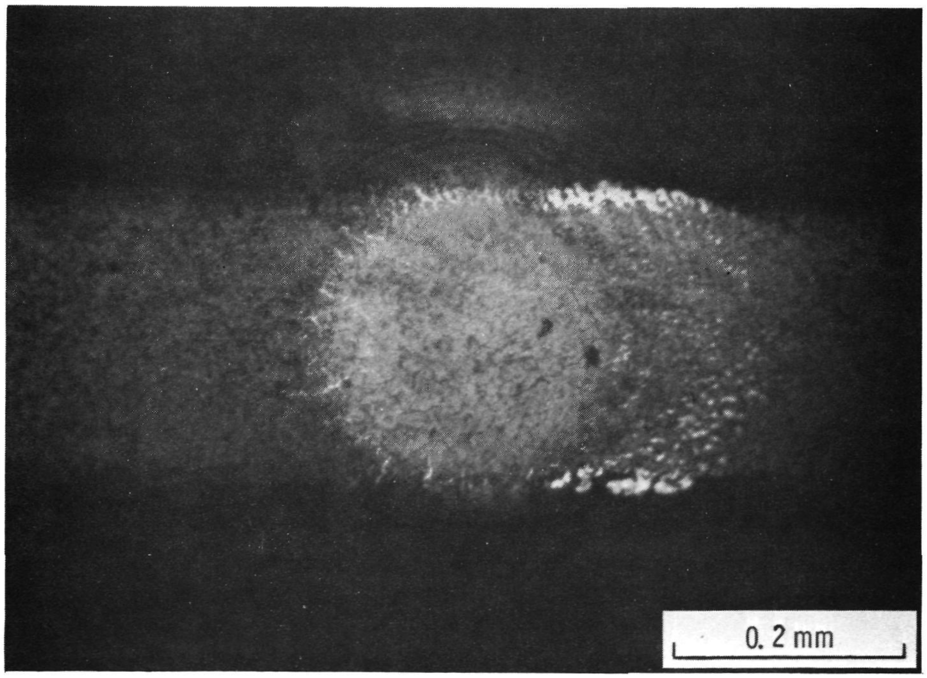
(b) 0.5 percent COARSE GRAPHITE IN 150 cS OIL.

Figure 2. - Graphite distribution during pure rolling, entrainment velocity, $\overline{U}$ = 0.0021 m/s, 2 kg load.

INLET SIDE HERTZIAN CONTACT EXIT SIDE

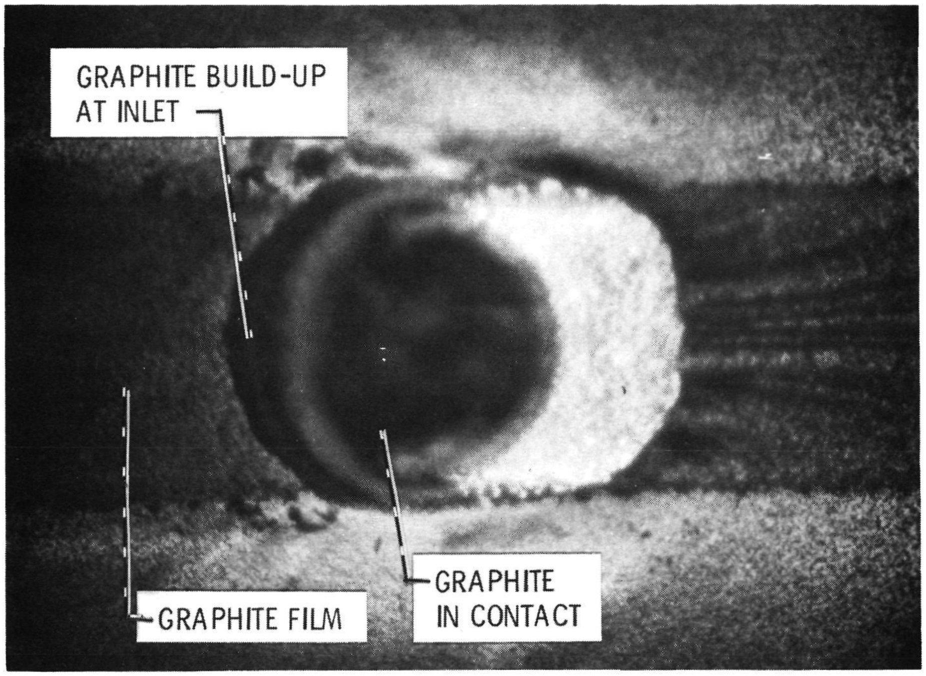


(c) 3 percent SUSPENSION GRADE GRAPHITE IN 78 cS OIL.

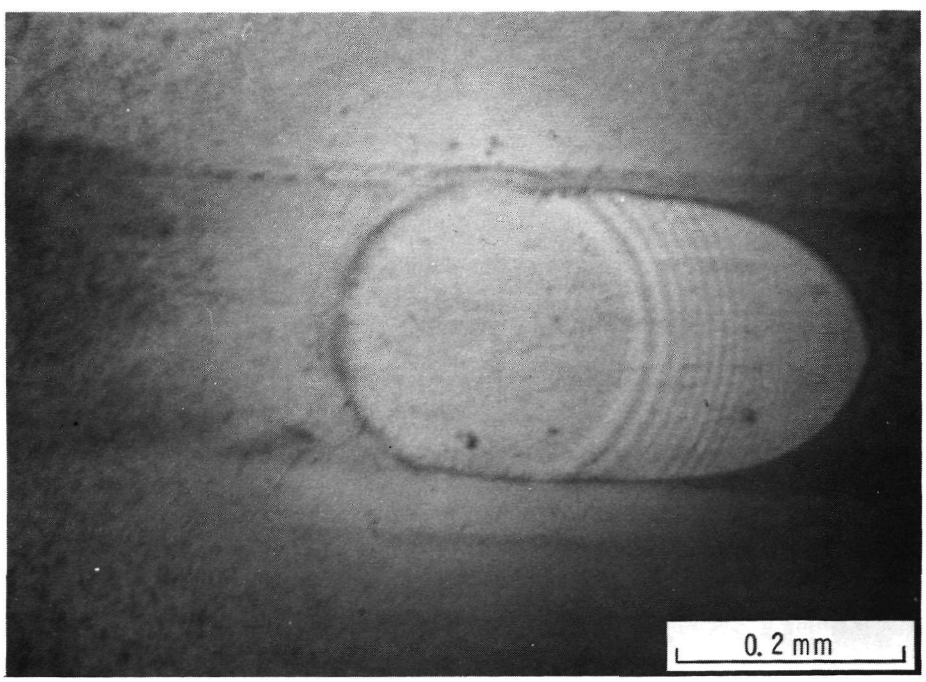


(d) 3 percent COARSE GRAPHITE IN 150 cS OIL.

Figure 2. - Concluded.

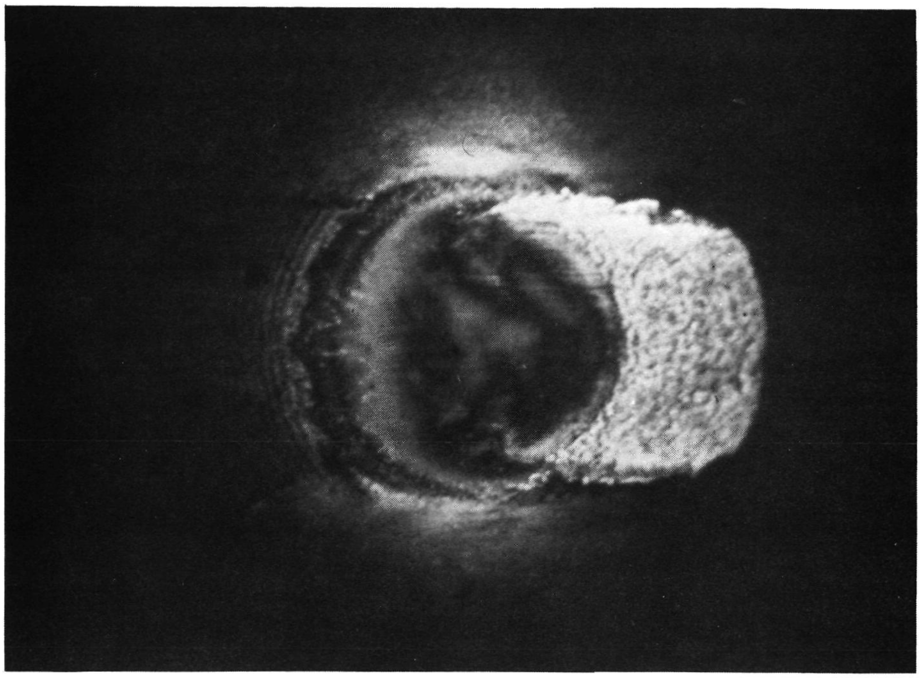


(a) 0.5 percent SUSPENSION GRADE GRAPHITE IN 78 cS OIL.

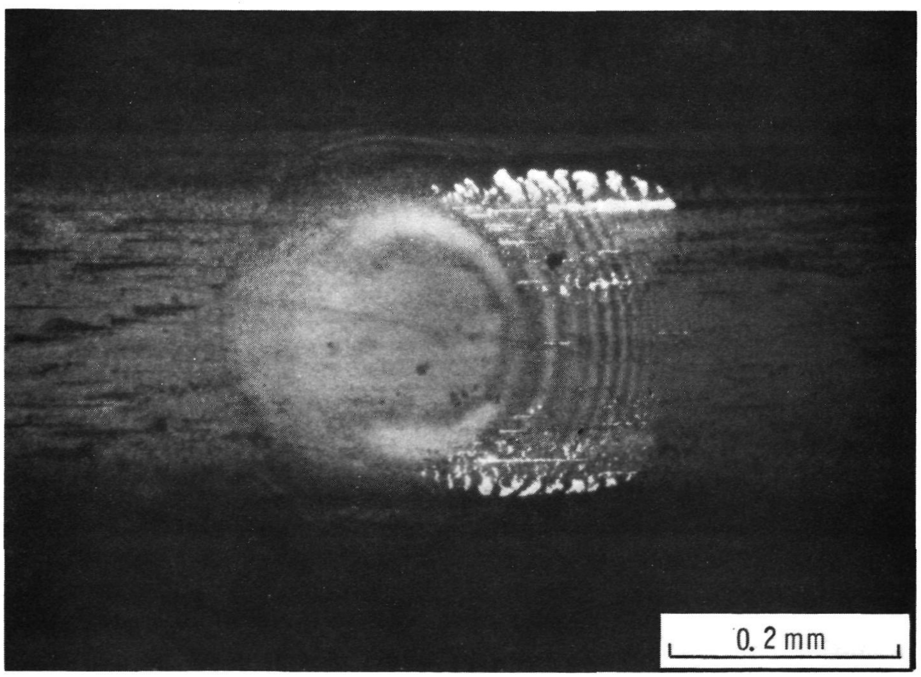


(b) 0.5 percent COARSE GRAPHITE IN 150 cS OIL.

Figure 3. - Graphite distribution at a slide/roll ratio, Σ = 1, U_1 = 0.0021 m/s, U_2 = 0.0007 m/s, entrainment velocity, $\overline{U}$ = 0.0014 m/s, 2 kg load.

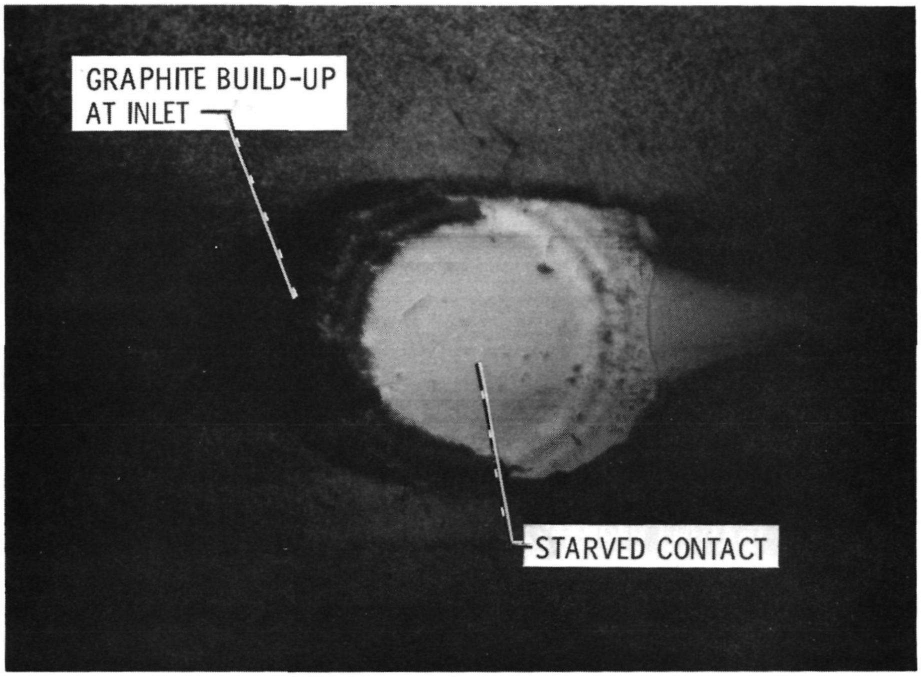


(c) 3 percent SUSPENSION GRADE GRAPHITE IN 78 cS OIL.

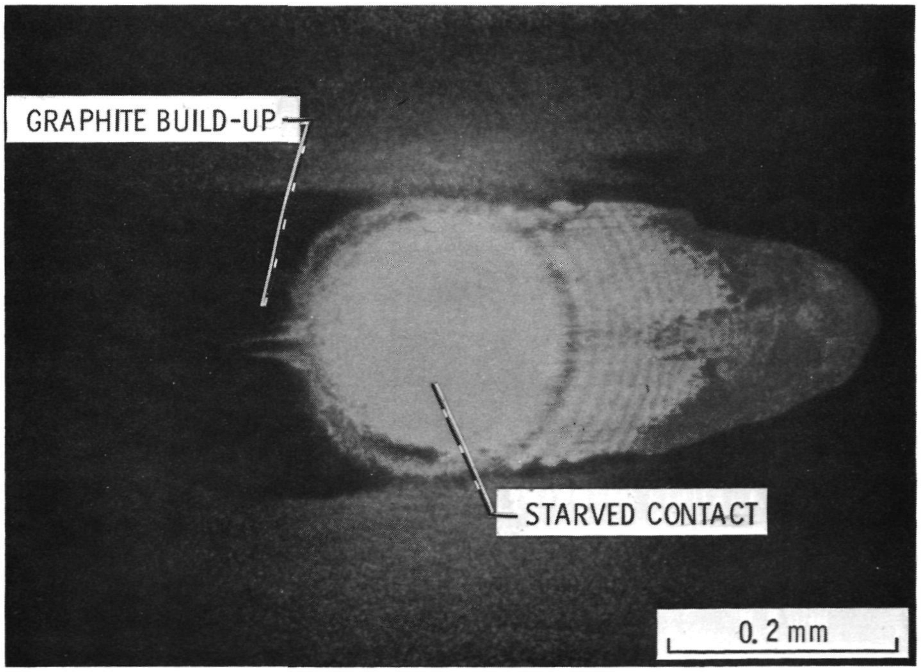


(d) 3 percent COARSE GRAPHITE IN 150 cS OIL.

Figure 3. - Concluded.

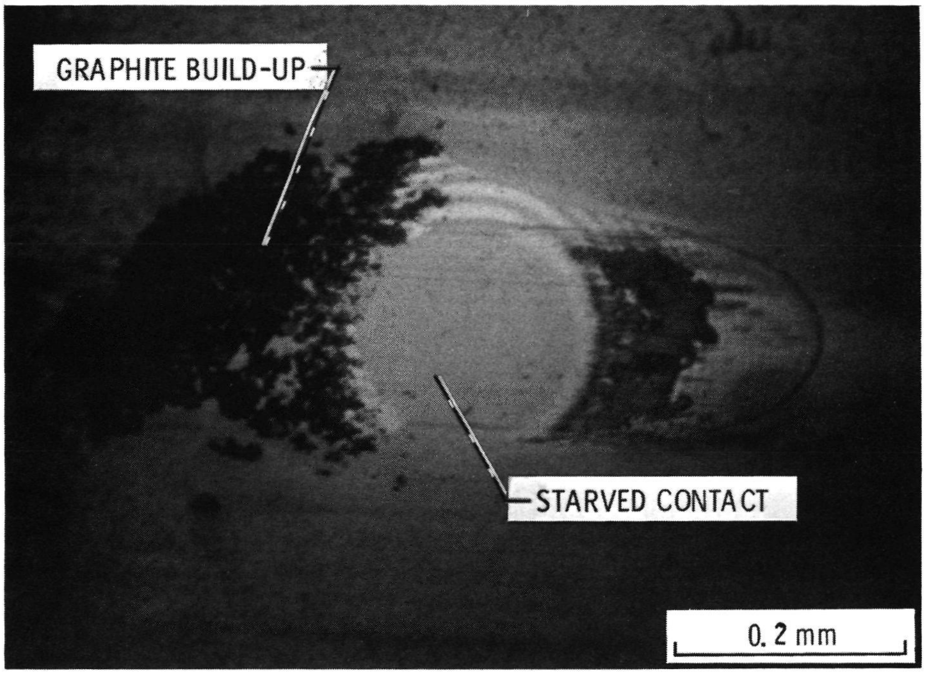


(a) 0.5 percent SUSPENSION GRADE GRAPHITE IN 78 cS OIL.



(b) 0.5 percent SUSPENSION GRADE GRAPHITE IN 150 cS OIL.

Figure 4. - Graphite distribution during pure sliding $U_1 = 0.0021$ m/s, $U_2 = 0$, $\overline{U} = 0.0011$ m/s, 1 kg load.



(c) 0.5 percent COARSE GRAPHITE IN 150 cS OIL.

Figure 4. - Concluded.

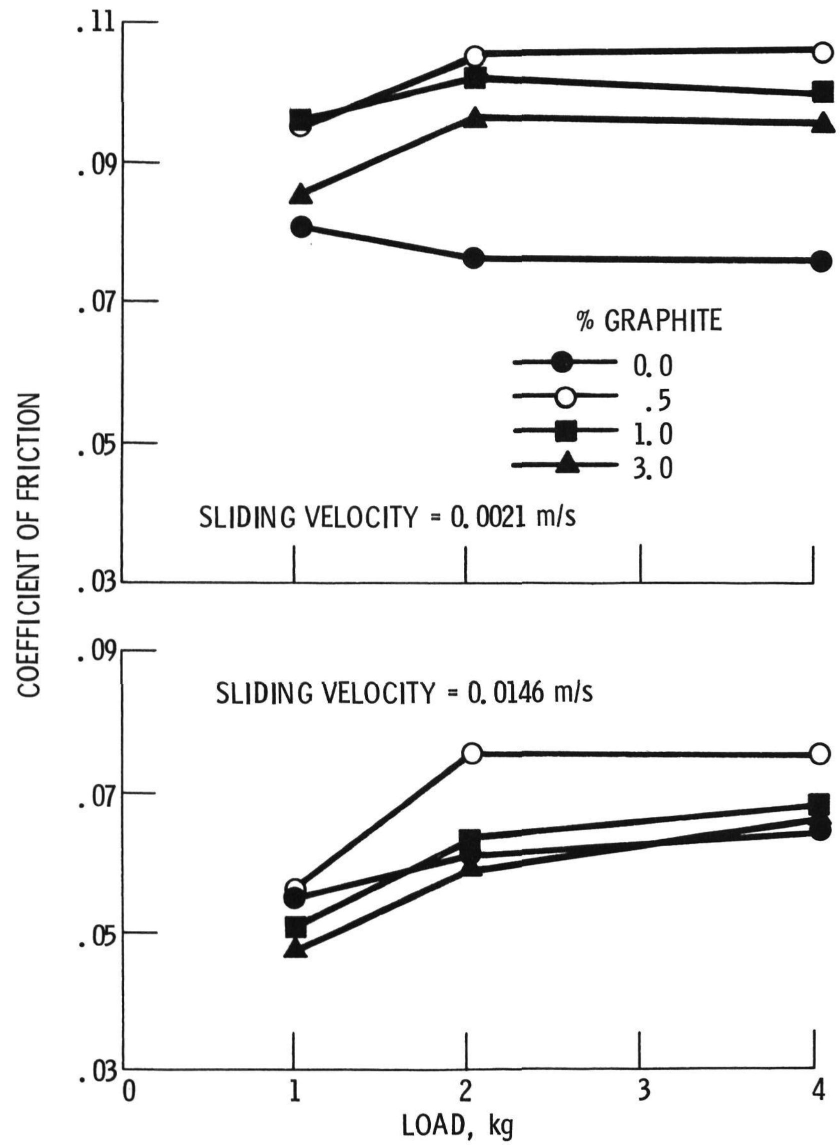


Figure 5. - Sliding fricition with suspension grade graphite in 78 cs oil.

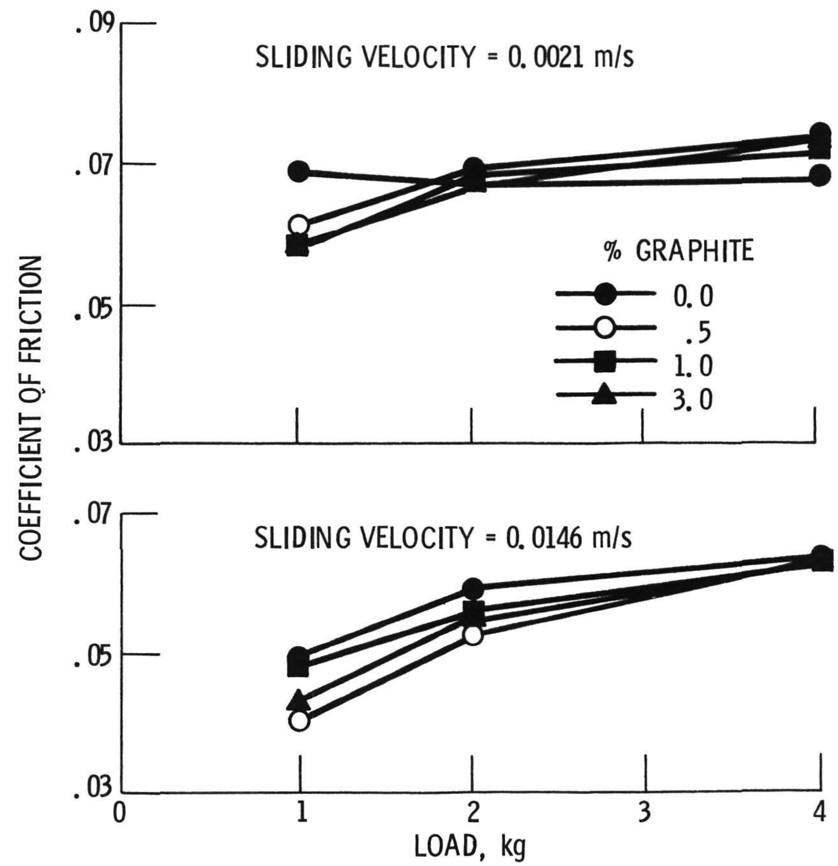
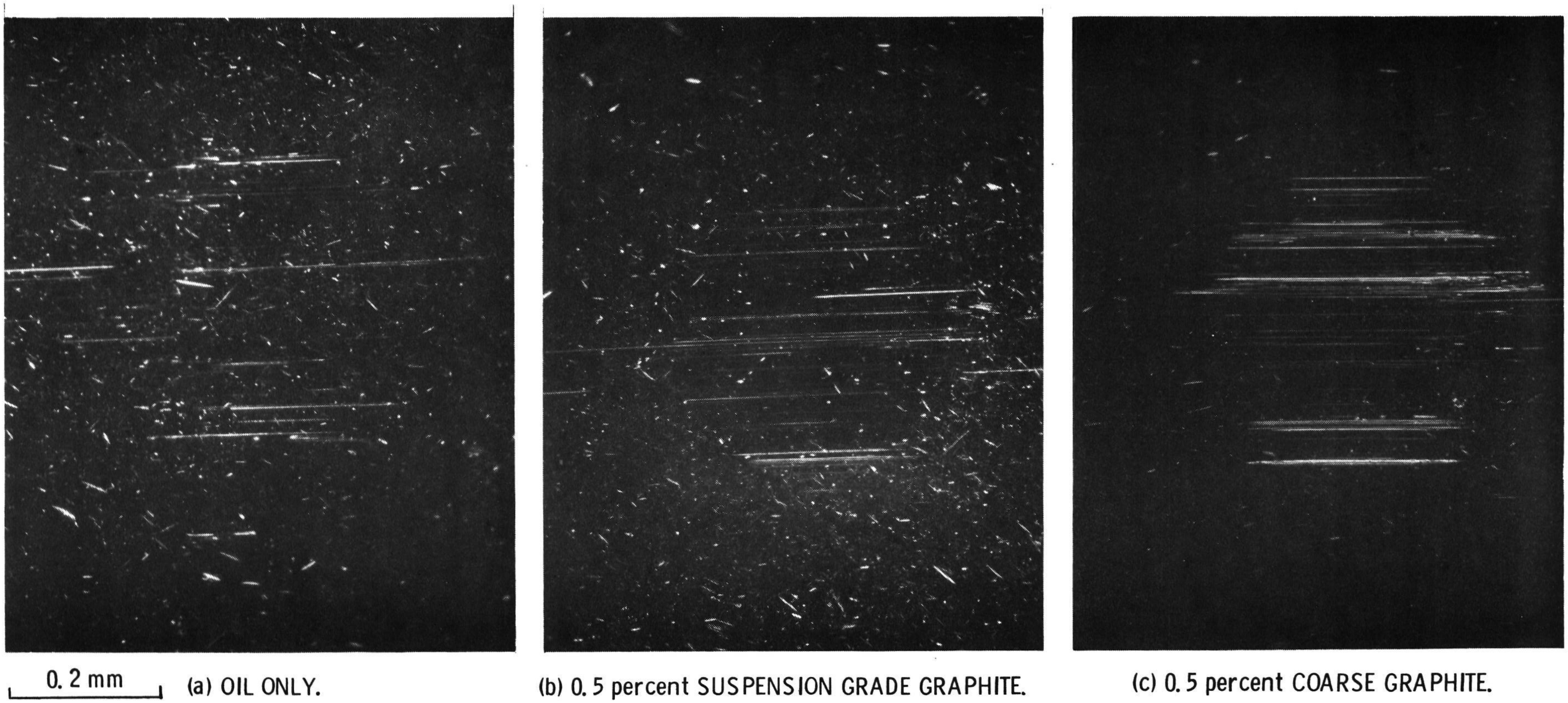


Figure 6. - Sliding friction with suspension grade graphite in 150 cs oil.



(a) OIL ONLY. (b) 0.5 percent SUSPENSION GRADE GRAPHITE. (c) 0.5 percent COARSE GRAPHITE.

Figure 7. - Effect of graphite in 150 cS oil on abrasion of polished steel ball during sliding contact.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-81683		

4. Title and Subtitle	5. Report Date
DYNAMICS OF SOLID DISPERSIONS IN OIL DURING THE LUBRICATION OF POINT CONTACTS, PART I - GRAPHITE	
	6. Performing Organization Code 505-32-42
7. Author(s) C. Cusano, University of Illinois, Urbana, Illinois and H. E. Sliney, Lewis Research Center, Cleveland, Ohio	8. Performing Organization Report No. E-410-1
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135	10. Work Unit No.
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	13. Type of Report and Period Covered Technical Memorandum
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared for the Annual Meeting of the American Society of Lubrication Engineers, Pittsburgh, Pennsylvania, May 11-14, 1981.

16. Abstract

A Hertzian contact is lubricated with dispersed graphite in mineral oils under boundary lubrication conditions. The contacts are optically observed under pure rolling, combined rolling and sliding, and pure sliding conditions. The contact is formed with a steel ball on the flat surface of a glass disk. Photomicrographs are presented which show the distribution of the graphite in and around the contact. In addition, friction and surface damage are shown for conditions when the base oils are used alone and when graphite is added to the base oils. Under pure rolling and combined rolling and sliding conditions, it is found that, for low speeds, a graphite film can form which will separate the contacting surfaces. In contrast, under pure sliding conditions, graphite accumulates at the inlet and sweeps around the contact, but very little of graphite passes through the contact. The accumulated graphite appears to act as a barrier which reduces the supply of oil available to the contact for boundary lubrication. Friction data show no clear short term beneficial or detrimental effect caused by addition of graphite to the base oil. However, during pure sliding, more abrasion occurs on the polished balls lubricated with the dispersion than on those lubricated with the base oil alone. All observations were for the special case of a highly-polished ball on a glass surface and may not be applicable to other geometries and materials, or to rougher surfaces.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Solid lubricant dispersions Graphite lubrication Boundary lubrication Lubricant particle dynamics	Unclassified - unlimited STAR Category 27

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161

National Aeronautics and
Space Administration

Washington, D.C.
20546

Official Business
Penalty for Private Use, $300

SPECIAL FOURTH CLASS MAIL
BOOK

Postage and Fees Paid
National Aeronautics and
Space Administration
NASA-451

U.S.MAIL

NASA

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return